Searching for a Gravitational Heating Signature in Nearby Luminous Ellipticals

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Abstract. We present a new deep optical study of a luminosity limited sample of nearby elliptical galaxies, attempting to observe the effects of gravitational interactions on the ISM of these objects. This study is motivated by recent observations of M86, a nearby elliptical galaxy that shows possible evidence for gas heating through a recent gravitational interaction. The complete sample includes luminous ellipticals in clusters, groups and the field. For each of the galaxies we objectively derive a tidal parameter which measures the deviation of the stellar body from a smooth, relaxed model and find that 73% of them show tidal disturbance signatures in their stellar bodies. This is the first time that such an analysis is done on a statistically complete sample and it confirms that elliptical galaxies continue to grow and evolve through gravitational interactions even in the local Universe. Our study of ellipticals in a wide range of interaction stages, along with available ISM data will attempt to shed light on this possibly alternative mechanism for maintaining the observed ISM temperatures of elliptical galaxies.

Keywords: elliptical galaxies: interactions, evolution, structure, ISM
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INTRODUCTION

Despite the relative simplicity of their stellar populations, elliptical galaxies vary significantly in their x-ray properties. The x-ray emission from giant ellipticals is dominated by radiation from a hot gaseous halo that engulfs the stars. Although gas is abundant in most of these systems, further star formation is suppressed by some mechanism which keeps the gas hot.

Recently it has been suggested that active galactic nuclei are responsible for supplying energy to the hot x-ray halos [e.g. 1] and for ionizing cold gas in their vicinity, thus creating the Hα filaments that are often observed in elliptical systems [e.g 2]. Alternatively, it was suggested that the source of these emission line filaments is cold gas accretion into the ISM of the galaxy by strong gravitational interactions and merger events [3]. In this scenario, gas is stripped from the colliding galaxy and gets heated up, perhaps through heat conduction, by the x-ray halo of the elliptical. Recent analytical studies have shown that minor mergers and low-mass clumpy accretion may be sufficient to keep the halos of ellipticals hot [4]. The interaction in this case transforms the initial potential energy of the accreted gas into thermal energy as it dissipates into the hot halo of the elliptical. The heating mechanism is therefore dynamical, consisting of weak shocks and/or ram-pressure drag to inject energy into both cold and hot interacting media. According to the gravitational heating model the interaction deposits energy into the ISM and heats it up, allowing for non AGN ellipticals to keep their x-ray halos hot.

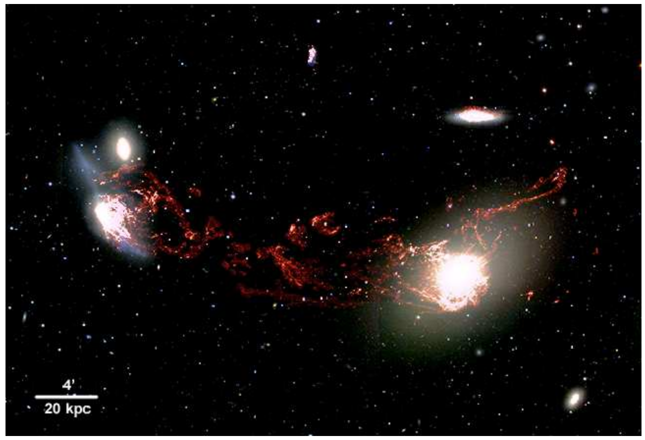

FIGURE 1. This continuum subtracted Hα+[NII] image of M86 and NGC 4438 may provide the first observational evidence of gas heating through gravitational interactions. The spiral is missing 95% of its cold gas.

EVIDENCE FOR GRAVITATIONAL HEATING

Suggestive evidence for gravitational heating comes from new observations of the Virgo galaxy M86 (figure 1) [5], where we have discovered a remarkable set of large scale Hα+[NII] filaments connecting the giant elliptical to NGC 4438, a spiral galaxy $\sim$23' ($\sim$120 kpc) away. Spectroscopy of the filaments show a fairly smooth velocity gradient between the galaxies, strongly suggesting a recent gravitational interaction between them. The data suggest that as NGC 4438 passed by M86 at high velocity, its cold gas was probably stripped by the ISM of the elliptical, causing the spiral to become HI-deficient. Despite being x-ray bright, M86 shows no clear signs for an active nucleus. Moreover, the total kinetic energy of the cold gaseous component of the spiral at closest approach was comparable to the current total thermal energy stored in the hot halo of the elliptical.

OBEY: OBSERVATIONS OF BRIGHT ELLIPTICALS AT YALE

We present a deep broadband optical imaging study of a complete sample of luminous elliptical galaxies ($M_B < -20$) at distances 15 Mpc - 50 Mpc, selected from the Tully catalog of nearby galaxies. The images are flat to $\sim$0.35% across the 20' field and reach a V band depth of 27.7 mag arcsec^{-2}. We derive an objective tidal interaction parameter for all galaxies and find that 73% of them show tidal disturbance signatures in their stellar bodies, in agreement with the findings of van Dokkum (2005) [6] who studied a sample of red galaxies at $z \sim 0.1$. This is the first time that such an analysis is done on a statistically complete sample and it confirms that tidal features in ellipticals are common even in the local Universe [7].

By comparing the tidal interaction parameter of the galaxies to their broad band optical colors we find that interacting systems are slightly bluer than non interacting ones, implying that these mergers are accompanied by little or no star formation. In

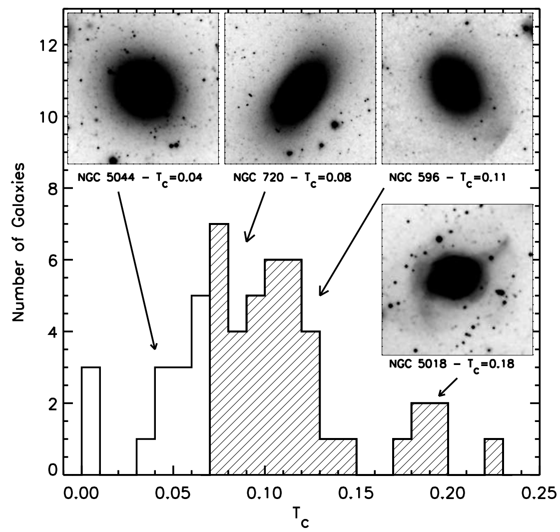

FIGURE 2. The distribution of derived tidal parameter values. The shaded area represents galaxies with a T_c value greater than the detection threshold. The four subset images are typical examples of various interaction levels.

fact, it appears that even the most interacting galaxies in our sample are red. This likely suggests that either very small amounts of cold gas are driven into the elliptical by the interaction or that star formation is suppressed as the accreted gas is heated and ionized by the collision.

TIDAL FEATURES AND THE AGN DUTY CYCLE

It has been suggested by several authors that gravitational interactions play an important role both in evolving elliptical galaxies [e.g. 8] and in triggering galactic nuclear activity in them. This is shown by a correlation between the brightness of elliptical galaxies in radio continuum observations and morphological disturbances [e.g. 9, 10].

We find no relation between the tidal parameter and radio continuum flux of our survey galaxies. Since the lifetime of the radio mode is only roughly 10^8 years [e.g. 1, 11], galaxies with a low tidal parameter are all expected to be quiet at radio wavelengths. The existence of radio-loud AGN in undisturbed ellipticals is very interesting and may imply that gravitational interactions are not the only and possibly not the most important AGN triggering mechanism.

GRAVITATIONAL INTERACTIONS AND ISM HEATING

Similarly to other ISM heating mechanisms gravitational interactions can potentially inject significant and sufficient amounts of energy into the hot halos of massive ellipticals. Simplified calculations, such as were demonstrated by Dekel and Birnboim (2008) show that an accretion rate of only $10^{-3} - 10\ M_{\odot}\ yr^{-1}$ would be needed to support a typical nearby halo. We have shown that the frequency of such collisions is high even in

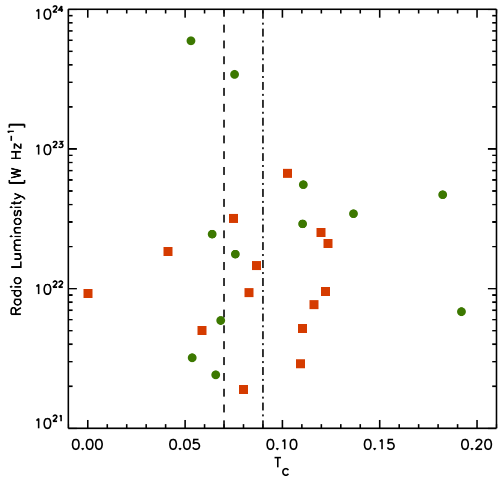

FIGURE 3. The relation between radio continuum flux and tidal parameter for 26 of the sample galaxies. The existence of radio-load, non-interacting galaxies suggests that gravitational interactions are not the only and possibly not the most important AGN triggering mechanism.

the local Universe and that more than two-thirds of all nearby massive ellipticals show disturbance signatures in their stellar bodies. However, not unlike other proposed ISM heating mechanisms (e.g., AGN, conduction, sloshing) the gravitational heating model lacks details regarding the specific energy transfer processes at work. In summary, although not a strong evidence for the importance of gravitational heating by itself, the implied interaction rate from our study suggests that mergers and accretion events are frequent enough to support such a model.

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